SYSTEM AND METHOD OF COOLING

FIELD OF THE INVENTION

The system and method of the present invention relates generally to the cooling of air and more particularly to a system and method of cooling air in systems including a heat exchange unit to effect heat transfer from a cooling fluid. The invention is particularly suited to cooling systems for relatively large volumes of air which is required in circumstances such as the cooling of air in large office buildings.

BACKGROUND OF THE INVENTION

Areas occupied by people generally require some form of heating and/or cooling in order to maintain the area at a reasonable temperature. In some instances, statutory or contractual arrangements require an area or premises to be maintained within certain temperature limits.

Accordingly, heating and cooling systems have developed over time and exist in most modern premises in order to maintain the temperature in those premises within predetermined temperature limits.

Heating and cooling large areas such as an office building usually requires a significant capital investment in the plant and equipment that affects the heating and/or cooling.

In warm climates, cooling systems incorporating a cooling tower have become a popular type of system for the cooling of large buildings. In this type of system, a refrigerant gas is used to cool air as it passes through a first heat exchange unit (evaporator) and having absorbed energy from the air, the refrigerant gas is passed to a second heat exchange unit (condenser) wherein heat is extracted from the refrigerant gas. The second heat exchange unit is supplied with water to effect cooling of the refrigerant gas and having absorbed energy, the water is generally transferred to a third heat exchange unit (cooling tower) in order to cool the water in preparation for further use. Whilst this type of system is commonly used for large office buildings, cooling towers unfortunately provide an environment conducive to the generation and distribution of a bacterium known as *legionella pneumophilia*. The bacterium becomes airborne and subsequent inhalation by people in the vicinity of a cooling tower may lead to the development of a disease commonly referred to Legionnaires' Disease.

The bacterium was first identified in Philadelphia, USA in July 1976 and since that time, infection in both sporadic and epidemic forms has occurred in Australia and many overseas countries. Epidemiological investigations have generally failed to identify the precise source of infection, however, cooling towers and water distribution systems are generally recognised as the most likely source. Legionnaires' Disease typically manifests itself as severe pneumonia with patients presenting early symptoms of malaise, muscle pains, headache and fever. Patients become increasingly short of breath and the respiratory symptoms progress to pneumonia, often culminating in respiratory failure. The development of Legionnaires' Disease is usually associated with mental confusion and delirium, vomiting and renal failure. The disease generally has an incubation period of 2 to 10 days and whilst the fatality rate from confirmed Legionnaires' Disease in Australia has decreased over the past six years, fatalities still occur. Legionnaires' Disease was proclaimed a Notifiable Disease in Australia in 1979 and all cases must be notified by health professionals to the relevant Heath Department upon detection.

Having recognised the propensity for cooling towers to generate and distribute the *legionella pneumophilia* bacterium, various approaches have been implemented to minimise the likelihood that towers form and distribute the bacterium. In particular, treatment of cooling tower water with corrosion inhibitors, surfactants, biocides and other chemicals is frequently proposed in order to reduce microbial growth.

Generally, a broad spectrum biocide is recommended for the water treatment process in order to reduce total microbial load in cooling tower water. However, in the dynamic environment of a cooling tower system, the performance of chemicals is different from that in controlled laboratory trials. For example, cooling tower water is subjected to temperature changes and varying flow velocities at different locations in the system. Many other parameters including pH level, conductivity, total dissolved solids, suspended matter and the biological mass within the system can also vary over time.

As a result, the efficacy of water treatment with a broad spectrum biocide cannot be predetermined for any particular environment and as such, ongoing sampling of cooling tower water is required to ensure that microbial growth has

been limited to an acceptable level in addition to any chemical treatment. Apart from the cost of the biocides, the requirement for ongoing sampling has the effect of significantly increasing the maintenance cost for a cooling tower system.

The use of ozone has also been proposed and has been successfully used in some instances to reduce microbial growth. Although ozone is an unstable chemical, it is a powerful oxidising biocide and must be produced on-site by means of an ozone generator and used immediately for water treatment. Ozone disinfection is relatively new for the control of bacterial levels in cooling tower waters and it is generally recognised that care must be exercised to maintain the generators in accordance with manufacturers' recommendations thus ensuring optimum efficiency. Apart from the significant capital investment required for an ozone generator, there remains some doubt as to the efficacy of this type of system for preventing microbial growth and the spread of Legionnaires' Disease.

The use of ultraviolet light has also been proposed for the reduction of bacterial levels in cooling tower water. With these types of systems, the cooling tower water is exposed to ultraviolet radiation of a sufficient intensity to eliminate bacterium in the water. It is important to ensure that the water is exposed to a sufficient level of ultraviolet radiation intensity for the system to be effective. Sensors are generally used to monitor the intensity of the ultraviolet radiation and any reduction in efficacy as detected by the sensors generally provides an indication that maintenance is required. Ultraviolet radiation has no effect on the pH, odour or chemical composition of cooling tower water. However, the colour, tepidity and chemical composition of the water can interfere with ultraviolet radiation transmission and as such, determination of the ultraviolet absorbency of the water to be treated prior to installing ultraviolet equipment is usually advisable. Bacteria may be protected by tepidity, clumping or the presence of slime and accordingly, appropriate water filtration is usually recommended in conjunction with ultraviolet radiation systems.

Despite implementing such a system to destroy bacterium, the ultraviolet damage to bacterium can be significantly reversed by enzyme repair mechanisms such as those that operate in darkness and on subsequent exposure to bright light (photoreactivation). Once again, the installation of an ultraviolet radiation

system involves a significant capital expenditure and is not an attractive option given that the efficacy of these systems is still currently questionable.

Various other proprietary devices have been proposed for the treatment of water including systems that expose the treated water to electromagnetic and electrostatic fields. There is a lack of conclusive scientific evidence to demonstrate that these proprietary devices have any significant affect on the microbial load in treated water. Survival and growth of the *legionella* bacteria in controlled laboratory field trials is currently being conducted for these systems.

Whilst filtration systems present the simplest method available for the reduction of microbial matter in water, a full-flow filtration plant that will remove fine particles is generally not practicable for most existing systems due to space and weight restrictions. Additionally, such filtration systems have associated installation and operational costs that generally render this approach economically infeasible. In any event, with any type of filtration system, there is necessarily an ongoing maintenance cost for backflushing and replacement of filters.

Irrespective of the water treatment systems currently in use, ongoing maintenance in the form of water sampling cannot be avoided and necessarily increases the ongoing maintenance cost for the operation of a cooling system incorporating a cooling tower.

In an earlier application, the present applicant disclosed an alternative arrangement for a cooling system that, under normal working conditions, eliminated the possibility of the cooling system generating air borne bacterium known as *legionella pneumophilia*. In particular, the applicant disclosed a cooling system including a cooling fluid heat exchanger that included a primary heat exchanger having a closed circuit for cooling fluid, an air cooler located upstream of the primary heat exchanger and a fan arrangement for forcing air through the cooler and the primary heat exchanger. In the arrangement previously disclosed, the air cooler included a moisture absorbent material that was maintained in a moist condition such that air forced through the cooler was cooled by the action of evaporation prior to being forced over a portion of the closed circuit in the primary heat exchanger.

Whilst this arrangement including a closed circuit for cooling fluid eliminated the possibility of the cooling system generating air borne *legionella pneumophilia* by retaining cooling fluid in a closed circuit, it was subsequently discovered that this arrangement suffered from a much reduced cooling capacity as compared with a cooling system of similar size operating in accordance with previously known solutions that included an open circuit for the cooling fluid.

In order to achieve the same cooling capacity as a prior art system, it was necessary to produce a significantly physically larger apparatus comprising a pre-cooler and closed circuit heat exchanger for cooling fluid.

The problem of reduced cooling capacity for an apparatus comprising a pre-cooler with a closed circuit heat exchanger is a substantial problem given that building management operators usually seek to replace or convert their existing open loop heat exchangers in order to eliminate the risk that their present cooling systems cause the generation of air borne *legionella pneumophilia*. In a large number of existing installations, the physical space available on a rooftop is limited and it is not possible to replace an existing open loop heat exchanger with a much larger closed loop heat exchanger arrangement. Further, there is a significant increase in the capital cost of an apparatus of this type with increased physical size.

However, the requirement for a cooling system to accommodate a particular cooling capacity is usually based upon the worst case conditions where the building is subject to a heat load that occurs during the summer period. In particular, it is not unusual for the maximum cooling capacity to only be required for approximately 15 to 20 days during any 365 day period.

Accordingly, it is an object of the present invention to provide a cooling system and method of cooling including a primary heat exchange unit having a closed circuit for cooling fluid with an air cooler located upstream of the primary heat exchanger and a fan arrangement for forcing air through the cooler and the primary heat exchanger with an improved cooling capacity as compared with previously disclosed systems of this type.

Any discussion of documents, act, materials, devices, articles or the like which has been included in the present specification is solely for the purpose of providing a context for the present invention. It is not to be taken as an admission

that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present invention as it existed before the priority date of each claim of this application.

SUMMARY OF THE INVENTION

In one aspect, the present invention provides a fluid cooling heat exchanger including:

a primary heat exchanger having a closed circuit for cooling fluid;

an air cooler located upstream of the primary heat exchanger;

a fan arrangement operable to force air through the air cooler and the primary heat exchanger; and

a liquid dispenser operable to dispense liquid into the forced air, said liquid dispensed downstream of the air cooler and upstream from the primary heat exchanger,

wherein said air cooler includes a moisture absorbent material that is, in use, maintained moist such that air forced through the cooler is cooled by the action of evaporation prior to being forced over a portion of the closed circuit in the primary heat exchanger.

Having a closed circuit for the cooling fluid as it passes through the primary heat exchanger ensures that the cooling fluid is prevented from exposure to the atmosphere, and in particular, to the air forced through the cooling fluid heat exchanger. This separation of cooling fluid as it passes through the heat exchanger from the forced air through the heat exchanger removes the risk of the generation and distribution of airborne legionella bacterium. In practice, the closed circuit is likely to form part of a loop within a cooling system where the cooling fluid is transported from a location where the fluid is used to absorb thermal energy and subsequently transported to the cooling fluid heat exchanger in order for the cooling fluid to release the absorbed thermal energy.

Whilst the invention is particularly useful for providing a heat exchanger which reduces the risk of the generation and distribution of airborne legionella bacterium, it has also been found that the liquid dispensers in combination with the moisture absorbent pads significantly improves the cooling capacity of the heat exchanger. Accordingly, the same cooling capacity can be produced from a substantially smaller heat exchanger, thereby reducing the capital cost of a heat

exchanger for a particular thermal load. Accordingly, the present invention is also useful in situations where cooling fluid other than water is used such as refrigerant.

Operation of the liquid dispenser improves the cooling capacity of the cooling fluid heat exchanger as compared with relying only upon the passing of forced cooled air over portions of the primary heat exchanger. As operation of the liquid dispenser has the potential disadvantage of leaving contaminant deposits on the primary heat exchanger (which can have the subsequent effect of reducing the heat exchange performance of the unit) the liquid dispensed is preferably only operated during periods in which a greater cooling capacity is required from the cooling fluid heat exchanger. However, in a further embodiment the liquid dispenser can also be used to permit washing on of an external surface of the primary heat exchanger. Washing of the primary heat exchanger reduces the amount of dust and dirt which can accumulate on the surfaces of the primary heat exchanger. Operation of the liquid dispenser to implement washing can be effected automatically at predetermined periodic intervals, and assists to maintain the thermal transfer performance of a heat exchanger.

Of course, it is preferable to use a liquid that is inexpensive and in plentiful supply. In a particularly preferred embodiment, the liquid used for dispensing is the mains supplied drinking water. However, this water usually contains contaminants that are in solution, such as calcium, that are very difficult to remove from the water. Filtration techniques that effectively remove contaminants that are "in solution" from water are generally quite expensive and are therefore usually considered economically infeasible. When mains supplied water is applied to a closed circuit cooling heat exchanger, subsequent to evaporation of the water, the calcium and other contaminants are usually left as deposits on the heat exchanger. The remaining deposits then prevent air flow over portions of the closed circuit heat exchanger and hence reduce the cooling efficiency of the unit. Eventually, heat exchangers will require maintenance to remove a build up of contaminant deposits in order to restore the unit to its original efficiency.

Accordingly, minimal use of dispensed liquid reduces the rate at which contaminants are deposited on the heat exchanger and hence reduces the rate at

which the heat exchanger requires maintenance to remove deposits. Operation of the liquid dispenser could be effected manually by activating the liquid dispenser during periods in which the ambient temperature, and hence heat load for a particular premises, is expected to require a greater cooling capacity from the cooling fluid heat exchanger than would be provided without operation of the liquid dispenser. However, in a preferred embodiment, the liquid dispenser is activated by a controller that senses the ambient environmental conditions and causes the dispenser to operate and dispense liquid into the forced air stream until such time as the additional cooling capacity provided by dispensing the liquid is no longer required. Operation of the liquid dispenser on this basis has the advantage of achieving the required increase in cooling capacity of the cooling fluid heat exchanger whilst maintaining the potential deposit of contaminants upon the heat exchanger to a minimum.

In a particularly preferred embodiment, the liquid is dispensed in a spray of fine droplets. Droplets of the dispensed liquid may become deposited upon portions of the closed circuit of the heat exchanger. As the liquid for dispensing is sourced from an alternative supply as compared with the cooling fluid, there is a substantially reduced risk that the dispensed liquid contains legionella bacterium. This is primarily due to the significantly lesser temperature of the dispensed liquid as compared with the temperature of the cooling fluid.

Further, in this embodiment, the spray is pulsed with intervening intervals where no liquid is dispensed. One particular approach to controlling the cooling capacity of the cooling fluid heat exchanger would be to adjust the duty cycle of the spray (i.e. relative period of on/off time) in accordance with the sensed ambient environmental conditions. In one particular embodiment, the temperature of the outgoing cooling fluid from the heat exchanger is measured and when the temperature exceeds a pre-determined first limit, the liquid dispenser is activated. The liquid dispenser is subsequently de-activated by the controller when the temperature sensed is lower than a second predetermined limit. Preferably, the pre-determined first limit is greater than the second pre-determined limit.

In an alternative embodiment, the pressure of the outgoing fluid from the heat exchanger is measured and when the pressure exceeds a first

predetermined pressure, the liquid dispenser is activated. The liquid dispenser is subsequently deactivated by the controller when the pressure sensed is lower than a second predetermined pressure. Preferably the first predetermined pressure is greater than the second predetermined pressure. In another embodiment, the liquid dispenser is also operated in very cold conditions when the ambient conditions approach the freezing point of the cooling fluid in the heat exchanger. In cold ambient conditions, the liquid in the dispensing apparatus will most likely be warmer than the primary heat exchanger. If the cooling fluid in the primary heat exchanger is allowed to freeze, the volumetric expansion of the fluid as it changes state from liquid to solid can cause the tubes in the heat exchanger to split and hence require replacement. Activating the liquid dispenser in such conditions, such that warm liquid is dispensed onto the primary heat exchanger, should prevent the cooling fluid from freezing. In a preferred embodiment, a temperature sensor connected to the primary heat exchanger measures the temperature of the body of the exchanger and sends a signal representative of the temperature to a controller such that the liquid dispenser is activated when the measured temperature falls to a pre-determined level. Alternatively, a temperature sensor could be placed in fluid communication with the cooling fluid.

In any event, it is important to control the amount of liquid deposited onto the primary heat exchange unit in order to control the impact of contaminants in the liquid that could alter the performance of the primary heat exchange unit.

In one embodiment, the cooled air emitted from the air cooler is substantially free of fluid in a liquid state in order to avoid the problem of fluid containments being deposited on the primary heat exchanger as a result of the action of the air cooler. In a particularly preferred embodiment, the air cooler and the primary heat exchanger are separated by a distance along the path of air flow from the cooler to the primary heat exchange unit to reduce the likelihood of fluid in a liquid state passing from the air cooler and impinging upon the primary heat exchange unit. As a result, the likelihood that liquid impinges upon the heat exchanger is only as a result of the action of the liquid dispenser.

Preferably, the heat exchange unit includes a plurality of air inlets and outlets with the fan arrangement disposed therebetween and operable to draw air in through the plurality of inlets and force air out through the plurality of outlets.

The air cooler may be located over the plurality of air inlets such that air drawn through the air cooler by the fan arrangement is cooled prior to being drawn or forced over the primary heat exchanger and subsequently through the plurality of air outlets.

Where the cooling fluid is water, the cooling water preferably passes through the primary heat exchanger in thermally conductive tubing, such as copper tubing, with drawn air passing over the tubing and removing thermal energy from the water passing through that tubing.

The air cooler preferably includes a water absorbent material similar to that used in evaporative cooling applications and may include wood fibre or cooling pad material such as that distributed under the trade mark "CELDEK". The moistened water absorbent material cools air passing through the material by the action of evaporation. This effect is used generally in evaporative cooling systems and water, separate from the cooling fluid, may be supplied to the water absorbent material using apparatus similar to that in current evaporative cooling systems.

Water is also the preferred liquid to be dispensed. Again, the depositing of water onto the primary heat exchanger does not pose any risk of generating or distributing air borne *legionella pneumophilia* as the water temperature would not rise to a sufficient level to prevent a risk.

The additional cooling effect of dispensing liquid into the forced air downstream from the air cooler yet upstream from the heat exchanger occurs as a result of various contributing effects.

Firstly, the dispensing of liquid into the air stream subsequent to the air cooler has the effect of increasing the saturation efficiency of the air cooler. For example, whilst the air cooler may have a saturation efficiency of 70 – 80%, the dispensed liquid may result in an increased saturation of greater than 80% which has the effect of reducing the dry bulb temperature of the forced air further as compared with the temperature of the air emitted from the air cooler.

Secondly, in the instance where dispensed liquid impinges upon the surface of the primary heat exchanger, there is a natural effect of thermodynamics wherein all bodies in thermally conductive contact with each other attempt to reach thermal equilibrium. In this instance, depositing relatively

cool dispensed liquid onto the surface of a relatively hot closed circuit heat exchanger will cause thermal energy to be removed from the heat exchanger and cause the temperature of the deposited liquid to rise. If the temperature rise of the deposited liquid is sufficient, the liquid may change state from its liquid state to a gaseous state.

Thirdly, the forcing of air through the heat exchanger and over the portions of the closed circuit heat exchanger that have liquid deposited onto them, reduces the vapourisation pressure of the liquid (i.e. the air pressure at which the liquid will change state from a liquid to a gas). A reduction in the vapourisation pressure increases the likelihood that deposited liquid will vapourise and hence increases the rate at which thermal energy will be extracted from the heat exchanger in order to enable the liquid to change state.

Generally, pads of water absorbent material would be located substantially vertically over the air inlets of the heat exchanger and water would be applied to an upper portion of the water absorbent pads and would migrate downwardly through and moisten the entire pad. In the event that water is applied to the absorbent material pad at a rate faster than evaporation therefrom, a holding tank may be suspended below the material pads in order to collect water run-off. Any water run-off collected in a tank may be reused by pumping that water back to the upper portion of the material pads for reapplication thereto.

In a particularly preferred embodiment, a water absorbent material pad including a plurality of fluted apertures of a size less than 7mm is used as part of the air cooler. Ordinarily in evaporative cooling applications, a water absorbent material pad with a plurality of 7mm fluted apertures is used. However, in this embodiment of the invention, use of a pad with fluted apertures of a size less than the standard size of 7mm has been found to provide a more efficient cooling effect. This particular embodiment also uses variable pitch fans for drawing air through the primary heat exchanger and through the air cooler pads. As a result of the increased efficiency resulting from the use of a pad with fluted apertures less than 7mm, the overall pad size may be reduced whilst still achieving the same cooling effect that of a pad with standard sized fluted apertures. A reduction in the overall size of an air cooler pad may be significant for installations where a conversion from an existing cooling tower arrangement is required and

there is limited physical space in which to install a new cooling fluid heat exchange unit.

In another embodiment, the cooling fluid comprises highly concentrated ammonia with a primary heat exchanger including stainless steel or aluminium tubing effecting passage of the ammonia through the heat exchanger. In this particular embodiment, the ammonia enters the primary heat exchanger in a gaseous state and upon having thermal energy removed, the ammonia is emitted in a liquid state. Whilst ammonia has previously been used as a cooling fluid, it has only been feasible for relatively large installations. As a result of the improved cooling efficiency from use of an air cooling stage and a liquid dispenser for dispensing liquid into the cooled forced air stream, an effective and economically feasible fluid cooling heat exchanger using ammonia as the cooling fluid may be produced for smaller installations. In one embodiment, the cooling fluid changes state during operation to effect transfer of thermal energy.

In another aspect, the present invention provides a method of cooling fluid in a cooling fluid heat exchanger, the method including the steps of:

passing cooling fluid of a cooling system through a primary heat exchanger having a closed fluid circuit such that the cooling fluid is contained;

locating an air cooler upstream of the primary heat exchanger and a liquid dispenser downstream of the air cooler; and

causing a flow of air through the air cooler and over a portion of the closed fluid circuit wherein said air cooler includes a moisture absorbent material that is, in use, maintained moist such that the air passing through the moisture absorbent material is cooled by vapourising the fluid contained therein and operating the liquid dispenser to dispense liquid into the forced air stream.

In a particularly preferred embodiment, the cooling fluid heat exchanger of the present invention is manufactured in a range of heat exchanging capacities such that a heat exchanger according to the present invention may be used to replace an existing cooling tower of a similar heat exchanging capacity.

In yet another aspect, the present invention provides a method of converting a cooling system incorporating a first heat exchanger including a fluid cooling heat exchange unit where the fluid is exposed to air drawn through the heat exchanger by replacing said first heat exchanger with a second heat

exchanger including a primary heat exchanger, an air cooler including a moisture absorbent material that is, in use, maintained moist such that air forced through the air cooler is cooled by the action of vapourisation and a liquid dispenser operable to dispense liquid into the forced air stream wherein the fluid in the primary heat exchanger is contained and prevented from exposure to air forced through the air cooler and then subsequently passed through the second heat exchanger, the method including of steps of:

disconnecting the first heat exchanger cooling fluid inlet and outlet connection;

reconnecting the fluid inlet and outlet to the corresponding connection points of the second heat exchanger; and

operating the cooling system.

In most conversions, it is likely that the first heat exchange unit will be removed to provide room for the second heat exchange unit although it is not essential.

In a further aspect, the present invention provides a cooling system having a fluid cooling heat exchanger including:

a primary heat exchanger including a closed circuit for cooling fluid;

an air cooler including a moisture absorbent material that is maintained moist for cooling air by evaporation said air cooler located upstream of said primary heat exchanger;

a fan arrangement operable to force air through said air cooler and said primary heat exchanger; and

a liquid dispenser operable to dispense liquid into the forced air stream;

wherein air forced through said air cooler is cooled prior to being forced over a portion of said closed circuit in said primary heat exchanger.

In yet a further aspect, the present invention provides a cooling system having a fluid cooling heat exchanger including:

a primary heat exchanger including a closed circuit for circulating fluid;

a secondary heat exchanger including a moisture absorbent material that is, in use, maintained moist, the secondary heat exchanger adapted to provide air cooled by the action of evaporation in communication with said primary heat exchanger; and

a liquid dispenser operable to dispense liquid into the forced air stream.

Throughout this specification the word "comprise", or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

BRIEF DESCRIPTION OF THE DRAWINGS

An example of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram illustrating the main components of a conventional cooling system including a heat exchange unit in the form of a cooling tower;

Figure 2 is a schematic diagram illustrating the main components of a cooling system incorporating an air-cooled condenser;

Figure 3 is a schematic diagram illustrating a cooling system incorporating a heat exchanger according to an embodiment of the present invention; and

Figures 4A and 4B are a side and sectional side view respectively of the heat exchange unit of Figure 3.

DETAILED DESCRIPTION OF THE INVENTION

With reference to Figure 1, a schematic diagram of a conventional cooling system incorporating a cooling tower is provided. This type of system is common for large buildings that have a relatively large space to cool and are usually arranged such that the majority of the cooling system is located in the basement of the building with a cooling tower situated on the roof of that building.

In Figure 1, a building 10 has an installed cooling system comprising a refrigerant gas circuit 12 passing through a condenser 14 and an evaporator 16. The flow of refrigerant gas through the circuit 12 is driven by a compressor 18 and regulated by expansion valve 20. Air in the building 10 is generally cooled by drawing air through a duct in which a portion of the chilled water circuit 22 resides. This process effects cooling of air in the building 10.

Refrigerant gas is passed through the condenser 14 for the purpose of cooling the refrigerant gas. Generally, in large buildings, the refrigerant gas is cooled by the use of water. Subsequent to absorbing thermal energy from the

refrigerant gas in the condenser 14, the water is transferred to a cooling tower 26 by way of a pump 24. As previously described, it is usual for cooling towers to be placed upon the roof of a building 10 as cooling towers are usually large and emit a substantial amount of noise during operation.

Hot water from the condenser 14 travels via pipe 28 to the water inlet of the cooling tower 26. The cooling tower 26 then extracts thermal energy from the water and cold water is drawn from the cooling tower 26 through pipe 30.

Cooling towers generally effect the removal of heat from cooling water by use of air flowing through the cooling tower to cause evaporation of a portion of the water. To evaporate some of the water, thus causing the water to transfer from a liquid to a gaseous state, thermal energy is required and this is extracted from the remaining water that continues to remain in a liquid state. Accordingly, as thermal energy is removed from the water and the temperature of the water in the tower decreases.

The most commonly used form of cooling tower uses induced draught counter-flow where air is drawn through the tower by a fan located at the discharge of the cooling tower. Air enters the tower through louvres and is drawn vertically through the tower in a direction opposite to the flow of cooling water through the tower. Another type of cooling tower has a fan mounted on one side of the tower with air either forced or induced through the tower in a cross-flow manner past falling water. In any event, all known types of cooling towers involve the exposure of cooling water to air drawn or forced through the tower and the storage of water in a basin for a period of time prior to that cooled water being drawn by the pump 24 through piping 30. This type of arrangement is common as it is relatively inexpensive to use a fluid such as water to effect heat exchange and to pump that water to a roof top mounted heat exchanger in order to cool the water.

Figure 2 illustrates an alternative conventional cooling system arrangement wherein the system comprises an enclosed loop of refrigerant gas 40 which is compressed by means of a compressor 42. The refrigerant gas is passed through an evaporator 46 where it absorbs thermal energy from a water circuit 48. The cooling of air in the building 35 occurs in a similar manner as for the system described in Figure 1. However, in contrast to the system of Figure 1, the system

illustrated in Figure 2 does not include a water cooled condenser and cooling tower arrangement for the purpose of removing thermal energy from the refrigerant gas. Instead, refrigerant gas is pumped from the basement of the building 35 up to the rooftop of the building and passed through an air cooled condenser 45. The air cooled condenser 45 includes electrically driven fans (47 and 49) for the purpose of drawing air through the air cooled condenser via air inlets and expelling the drawn air through air outlets.

Generally, refrigerant gas is contained in thermally conductive piping that is formed in a tortuous path which resides within a region of the air cooled condenser 45 and is subject to airflow.

The type of cooling system illustrated in Figure 2 is usually used in installations where the distance between the plant room and the air cooled condenser is sufficiently short to do so. If the distance is too long for it to be feasible to transfer gas, then an alternative arrangement is sought. In most instances where a heat exchange unit will be mounted on the roof top of a building, the distance from the plant room to the heat exchange unit is sufficiently long to render this type of system infeasible.

An embodiment of the present invention is illustrated in Figure 3 wherein a cooling system for a building 50 includes an enclosed circuit of refrigerant gas 52 that is passed through a condenser 54 and an evaporator 56 by a compressor 58. The flow of gas through the enclosed circuit 52 is controlled by an expansion valve 60. The evaporator includes an enclosed water circuit 62 which has thermal energy removed therefrom in order for the enclosed water circuit 62 to be used to effect cooling of the air in the building 50 in a similar manner as described previously (refer Figure 1). As for the system illustrated in Figure 1, the condenser 54 operates as a heat exchanger to extract thermal energy from the enclosed loop of refrigerant gas 52.

The removal of thermal energy from the enclosed loop of refrigerant gas 52 in the condenser 54 is effected by the use of another fluid, usually water, which is drawn into the condenser 54 through piping 66 and carried out of the condenser 54 through piping 68. Cooling water is drawn into the condenser 54 and passed through it under the control of pump 70. Water emitted from the

condenser 54 is carried by piping 68 to the rooftop of the building 50 where it enters a rooftop mounted heat exchanger 75.

The heat exchanger 75 includes electrically driven fans (77 and 79) that operate to draw air therethrough. The piping 68 is generally thermally conductive and formed in a tortuous path with that portion formed in a tortuous path disposed in a region that will be subject to air flow as air is drawn through the heat exchanger 75. Along the portion of the piping that is formed in a tortuous path, thermally conductive extensions may be connected to the piping 68 in order to improve the efficiency of removing thermal energy from the water in the piping 68 as air passes over the piping 68 and the thermally conductive extensions. Usually, thermally conductive extensions comprise heat fins formed from a suitably thermally conductive material. Having passed through the portion of piping formed in a tortuous path, the water is then carried out of the rooftop mounted heat exchanger 75 via piping 66 and is once again pumped into the condenser 54 by action of the pump 70.

In addition to passing cooling water through a portion of piping subject to forced airflow, the rooftop mounted heat exchanger 75 also includes moistened water absorbent material suspended over the air inlets of the heat exchangers 75 such that air drawn through the moistened water absorbent material is cooled by the action of evaporation prior to that air passing over the portion of piping 68 formed in a tortuous path. As a result of cooling air prior to passing it over piping carrying water emitted from the condenser 54, the effectiveness of removing thermal energy from that fluid is significantly increased.

Although Figure 3 does not detail the liquid dispenser, Figures 4A and 4B provide a side view and a sectioned view of the heat exchanger 75 and detail the location of the liquid dispensing apparatus as it is located in a preferred embodiment of the invention.

With reference to Figure 4B, the heat exchanger 75 includes electrically driven fans (77 and 79) arranged to draw air through the heat exchangers 75. The side walls of the heat exchanger (82 and 84) comprise thermally conductive piping formed in a tortuous path carrying water from the condenser 54 the piping residing in a region subject to air flow through the heat exchanger 75. The thermally conductive piping is wound through a tortuous path to extend

substantially over the entire region subject to airflow and in the sectional view of Figure 4B, the piping extends substantially perpendicularly into and out of the plane of the diagram.

In the embodiment of the heat exchanger 75 as detailed in Figure 4B, the side walls 82 and 84 effectively form two banks of the heat exchangers, each acting to remove thermal energy from the water passing therethrough. In this respect, water enters the heat exchange banks 82 and 84 through inlets 68 and 68a and having passed through the respective heat exchange banks are emitted therefrom through corresponding outlets 66 and 66a. Water enters the heat exchange banks 82 and 84 through inlets 68 and 68a in a "hot" state and having had thermal energy extracted therefrom, the water is emitted from the heat exchange banks 82 and 84 through outlets 66 and 66a in a "cold" state. Of course, the inlets, 68 and 68a, may be connected by a common header. Similarly, the outlets, 66 and 66a, may also be connected to a common header.

Whilst thermal energy would be extracted from water passing through the heat exchange banks 82 and 84 solely by action of air drawn through those heat exchange banks, the efficiency of the extraction of thermal energy from water passing through the heat exchange unit is significantly improved by suspending moistened water absorbent material over the air inlets of the heat exchanger 75.

With reference to Figure 4B, water absorbent material pads 85 and 87 are suspended over the air inlets of the heat exchanger 75 such that air passing over the heat exchange banks 82 and 84 is required to pass through the water-absorbent material pads 85 and 87 first.

In a preferred embodiment, the water absorbent material pads 85 and 87 comprise material distributed under the trademark "Celdek" and these pads 85 and 87 are continually moistened by the application of water to the top of each of the pads 85 and 87 at inlets 90 and 92. Water applied at inlets 90 and 92 eventually trickles down through the water absorbent material pads 85 and 87 substantially wetting the entire material pad. In the event that the material pads 85 and 87 do not fully absorb water applied to the inlets 90 and 92, run-off from the bottom of each pad may be collected in a tank (not detailed herein) that may be returned to the water inlets 90 and 92 via a pump (also not detailed).

Air drawn through the material pads 85 and 87 is cooled by the action of evaporation and the passing of this cooled air over the heat exchange banks 82 and 84 acts to significantly increase the efficiency of the extraction of thermal energy from water passing through those heat exchange banks.

In a particularly preferred embodiment, a water absorbent material pad comprising a plurality of fluted apertures of a size less than 7mm in diameter is used as part of the air cooler.

Even though a heat exchanger of certain physical dimensions that has cooled air used to extract thermal energy from the heat exchange banks 82 and 84 results in an increased cooling capacity as compared with an arrangement without an air cooler, the resulting improvement in cooling capacity may not be sufficient for all ambient conditions. The cooling capacity of such an arrangement can be improved by producing a physically larger unit with a longer tortuous path for the water to travel through a heat exchange bank and with larger material pads through which cooled air would be drawn. However, there is a significant increase in cost associated with an increase in the physical dimensions of such a heat exchanger. Although increased physical dimensions result in an increased cooling capacity, the increased cooling capacity may only be required for a relatively short amount of time during the operational life of the heat exchanger.

In this instance, the significant increase in cost to produce a physically larger unit to provide the required maximum cooling capacity is difficult to justify and is usually considered to be an economically infeasible proposition. Further, where a heat exchanger according to the present invention is proposed to be installed as a replacement for an existing prior art heat exchanger, physical space may be limited and replacement of an existing heat exchanger with a much larger unit may not be possible.

The present invention overcomes this problem by increasing the cooling capacity of the heat exchanger without the need to increase the physical dimensions of the unit. In this respect, the inclusion of a liquid dispenser that operates to deposit liquid into the forced air flow between the air cooler and the primary heat exchanger assists the process of extracting more thermal energy from the heat exchanger.

In one preferred embodiment, dispensed liquid is deposited onto the closed circuit heat exchanger and in this instance, this operation can result in the deposition of contaminants contained in the liquid that remain on the heat exchanger after the liquid has evaporated. When the liquid is water, the primary contaminant that remains after evaporation is calcium which can build up over time and form a thermally insulating layer on the surface of the heat exchanger. Such deposits can also build up to a sufficient extent that blocks air passages through the heat exchanger. Where the heat exchanger has finely spaced heat dissipating fins, calcium deposits can easily block the air passages between fins and reduce the efficiency of the heat exchangers operation. Further, contaminants can cause corrosion of the material of the primary heat exchanger thus reducing the operational life of the heat exchanger.

Whilst it is preferable to avoid contaminant deposits on a primary heat exchanger, the present invention substantially reduces the incidence of contaminant deposits by only activating the liquid dispenser at those times when an increased cooling capacity is required. Accordingly, the present invention achieves an increased cooling capacity whilst minimising the deposition of contaminants onto the primary heat exchanger.

With reference to Figures 4A and 4B, inlets 95 and 96 in conduits 101 provide a passage for liquid to travel to the liquid dispensers 98 and 99. An electrically controlled valve 103 is located in each conduit 101 to selectively permit liquid flow to a respective dispenser 98, 99 in response to a signal from the controller. Each respective conduit 101 extends substantially upwardly from a respective dispenser 98, 99 such that during periods when the valve 103 is closed, any fluid in the conduit 101 between the valve 103 and the dispenser 98, 99 drains through the dispenser outlet. Ensuring that water does not collect and reside in any of the conduits supplying dispensing outlets, further minimizes any risk of generation of the legionella pneumophilia bacterium. In the embodiment of Figures 4A and 4B, the dispensers 98 and 99 emit liquid as a spray of tiny droplets which are then forced by the air flow through the heat exchanger such that a portion collide with, and are deposited on, the external surface of the primary heat exchanger. Evaporation of the liquid droplets causes an increased

extraction rate of thermal energy from the primary heat exchanger as compared with the passage of cooled air alone.

In a particularly preferred embodiment, the heat exchanger includes a controller that activates the liquid dispenser during periods when an increase in cooling capacity is required. For example, the control methodology could pulse liquid from the dispensers for a short period of time on a regular or periodic basis when the temperature of the cooling fluid emitted from the heat exchanger rises above a first pre-determined limit. For example, the first predetermined limit could be 31°C. The dispensers being activated when cooling fluid temperature is above the first limit until such time that the temperature of the cooling fluid emitted from the heat exchanger drops below a second predetermined limit. The second predetermined limit is preferably at least 2°C below the first predetermined limit temperature to avoid the dispensers being constantly activated and deactivated in response to small fluctuations in the temperature of the cooling fluid around the predetermined limits.

A similar approach is taken when activating the dispensers near the freezing point of the cooling fluid. In this instance, the dispensers are activated when the ambient temperature drops below a third predetermined limit. The third predetermined limit could be 3°C. The dispensers remaining activated until such time as the ambient temperature exceeds a fourth predetermined limit which may be approximately 5°C.

Alternative control methodologies could be employed with the objective being to operate the dispensers for the least required time to accommodate the requirement for an increased cooling capacity for the period of time that the increased cooling capacity is required.

In a particularly preferred embodiment, variable pitch fans are used to draw air through the primary heat exchanger and the air cooler pads. The use of a water absorbent material pad with apertures of a diameter less than the standard diameter results in a more efficient air cooling effect and as such, the overall size of the water absorbent material pad may be reduced whilst still providing a similar cooling effect as a pad with larger apertures. A reduction in overall pad size may be critical for installations where the heat exchange unit must conform to physical space restrictions. In these instances, a reduced

overall pad size may result in a heat exchange unit according to the present invention being a feasible option for that particular installation.

In a further embodiment, the cooling fluid comprises highly concentrated ammonia with a primary heat exchanger comprising stainless steel or aluminium tubing effecting passage of the ammonia through the heat exchanger. Whilst ammonia has previously been used as a cooling fluid, it has generally been restricted for use in very large installations. However, the improved cooling effect of a heat exchanger according to the present invention enables the construction of a heat exchanger, comprising an ammonia cooling fluid, of a reduced physical size with a similar cooling capacity as that for a larger sized conventional heat exchangers. As a result, heat exchangers using ammonia as the cooling fluid become a more economically feasible option for relatively small installations.

CONCLUSION

The present invention embodies many advantages, the most significant of which being the provision of an alternative heat exchanger that does not present a risk of generating and distributing airborne *legionella* bacterium. A heat exchanger according to the invention may be used to replace existing cooling tower heat exchangers. In this respect, whilst many approaches have been proposed for overcoming the disadvantages of cooling towers and their susceptibility to generate and distribute the *legionella* bacterium, most of these approaches involve a substantial increase to the ongoing maintenance cost of the cooling system.

In contrast to most prior proposals, the present invention maintains cooling fluid in an entirely closed circuit such that the cooling fluid is not exposed to the environment or the atmosphere. As such, the possibility of the cooling fluid distributing legionella bacterium into the environment in a system according to the present invention and under normal working conditions is completely eliminated.

The inclusion of a liquid dispenser operable to dispense liquid into the forced air stream between the air cooler and the primary heat exchanger to increase the cooling capacity of a unit enables the physical dimensions of a heat exchanger according to the present invention to be constrained whilst still able to provide the necessary cooling capacity during peak heat loads.

Additionally, the arrangement of the current invention lends itself particularly well to the replacement of existing cooling tower arrangements by maintaining the use of a condenser in the basement of a building and the pumping of cooling fluid to a rooftop heat exchanger. In particular, the conversion of an existing cooling system arrangement incorporating a cooling tower to a system according to the present invention is relatively easily effected by the disconnection of water inlet and outlet conduits from the existing cooling tower, removal of the cooling tower and replacement therewith by a heat exchanger according to the present invention and reconnection of the fluid conduits.

Further, the activation of the liquid dispensers in very cold conditions when the ambient temperature approaches the freezing point of the cooling fluid, assists in preventing the cooling fluid from changing state from a liquid to a solid. Accordingly, the likelihood to the tubes in the heat exchanger splitting due to volumetric expansion of cooling fluid is minimized. In addition, the activation of the liquid dispensers to facilitate washing of the external surface of the primary heat exchanger reduces the amount of dust and dirt which can accumulate and subsequently assists to maintain the thermal transfer performance of the heat exchanger.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.